Engineering Note
for
E906 Detector Assembly

PROJECT: E906

TITLE: Station 3-Plus Drift Chamber

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ABSTRACT: This document describes an I-beam framework which will be attached to a drift chamber and hung in the E906 beamline.

DESIGN:
The Station 3-Plus drift chamber was designed and built by the Tokyo Institute of Technology. The weight of this chamber is approximately 770 pounds. There are two steel hanger blocks attached to the top of this chamber which will be bolted to a turnbuckle and I-beam assembly shown in Figure 1. The entire package will be inserted into the beamline by resting the ends of the bottom surface of the aforementioned I-beam (type S8 x 6.35) onto the top surface of a pair of cantilevered steel I-beams that are part of an existing structure in the experimental hall.

ANALYSIS:
The drift chamber and I-beam assembly from Figure 1 will be inserted into the beamline by wrapping slings around the I-beam and using the crane in NM4. The hanger block, turnbuckle adapter, turnbuckle, I-beam, and all the fasteners must be strong enough to hang vertically for the duration of the experiment. Each of these components is analyzed separately as follows:

HANGER BLOCK:
The hanger blocks are machined from solid pieces of steel (type S45C) and are attached to the drift chamber frame using eight (8) 3/8-16 bolts. See Figure 2. The load on each hanger block is 385-lbs. Therefore the load on each of the 3/8-16 bolt is 48.125-lbs. These bolts are always in shear. With a minor diameter of 0.2970" and an area of 0.069-in^2, the resulting shear stress in each 3/8-16 bolt is roughly 697.5psi. Grade 5 (alloy A325) bolts are readily available. The allowable shear for these bolts, per the Manual of Steel Construction 9th edition, is 17ksi which is far in excess of these expected actual values. These same hanger blocks are attached to the turnbuckle assembly via an adapter block using a single ¾-10 bolt, in shear. The load on each of these ¾-10 bolts is 385-lbs. With a minor diameter of 0.6255" and an area of 0.307-in^2, the resulting shear stress in each 3/4-10 bolt is roughly 1254psi which is also acceptable for Grade 5 fasteners. The ¾-10 tapped hole through the hanger block is also subjected to a tear out stress from the bolt equal to the load divided by the effective cross sectional area. The magnitude of this tear out stress, per Figure 2, is 67.78psi. Type S45C steel has yield strength of 45ksi. Assuming shear strength is 40% of yield strength results in an allowable shear of 18ksi which is also far in excess of the expected actual value.

When the chamber is hanging in the beamline the hanger block will experience stress and deflection from the weight of the drift chamber. If treated as a beam simply supported at both ends subject to a concentrated load at the center then the stress and deflection of the hanger block can be calculated using standard formulas:

Stress at center of constant cross section: $$s = \frac{-WL}{Z} \quad \textbf{(1)}$$

Maximum deflection at center: $$y = \frac{WL^3}{24EI} \quad \textbf{(2)}$$

Where: W is the weight of each load (385-lb)
L is the length of the block (9.45 inches)
I is the moment of inertia of the block (2.14in^4, per Fig. 2)
Z is the section modulus
E is the modulus of elasticity of S45C steel (29.1e8 psi)

Substituting the values from Table 1 into equation (1) yields:

$$s = -\frac{385lb \times 9.45in}{\left(2.14in^4 \big/ 1.28in\right)} = -2176.1lb/in^2$$

Likewise, substituting the values into equation (2) yields:

$$y = \frac{1}{24}\left[\frac{385lb \times (9.45in)^3}{29.1e8psi \times 2.14in^4}\right] = 0.000002in$$

The bending stress of 2176.1psi and deflection of 2e-6 inches are not cause for concern.

TURNBUCKLE ADAPTER:
The turnbuckle adapters are made of type 1018 steel an yield strength of 32ksi. See Figure 3. These adapter blocks have a 0.5" diameter hole at the top to connect to the turnbuckle and a pair of 0.78" diameter holes at the bottom through which the ¾-10 bolt is inserted through the hanger block. These holes are all subjected to a tear out stress. From Figure 3, the magnitude of the stress for the 0.5" diameter hole is 641psi and that of each 0.78" hole is 158psi. Once again, assuming that shear strength is 40% of yield strength results in and allowable shear of 12.8ksi and these tear out stresses are acceptable.

TURNBUCKLE ASSEMBLY:
The turnbuckles connect the adapter block to the vertical part of the I-beam assembly. They are purchased from McMaster Carr (part number 3022T54) and have a certified work load limit of 2,200 pounds. The actual load on each turnbuckle is only 385 pounds and is well below this limit.

I-BEAM:
The I-Beam assembly is made of Aluminum type 6061. The vertical portion of the I-beam assembly is shown in Figure 4. The main component of this is a segment of S8x6.35 aluminum I-beam. A plate, 0.5 inches thick, is welded to each end of this segment and a hanger block is welded to the bottom plate. There is a 0.38" hole in the bottom of this hanger block that is connected to the turnbuckle. The load on this hole is 385 pounds and the tear out stress is 726psi. The yield shear strength of this alloy is 20ksi and the tear out stress is of 736psi acceptable. The other end of this block is welded to the endplate, all around, with a fillet weld. The weld has a minimum leg size of 0.25" which corresponds to a minimum throat of 0.177". The effective throat area of this weld is 0.742-in^2 and the 385 pound load results in a shear of 457psi. The filler material is ER4043 and the allowable shear for this type of weld (Aluminum Design Manual, Part VI, 2010) is 5.9ksi which is well in excess of the expected actual value.

The endplates are similarly welded to the web of the I-beam on each side. The throat of these welds is also 0.177" and the total length of both welds is 17.3" giving an effective throat area of 3.07in^2. This leads to a shear of 126psi which is also acceptable for this type of weld.

The vertical portions of the I-beam assembly are attached to a long aluminum I beam using four (4) 3/8-16 bolts. See Figure 1, Detail B. The load on each connection is 385-lbs. Therefore the load on each of the 3/8-16 bolts is 96.25-lbs. These bolts are always in tension. With a tensile stress area of 0.0774-in^2 each of these bolts experience a tensile stress of 1244psi. The allowable tension for these bolts, per the Manual of Steel Construction 9th edition, is 44ksi which is far in excess of these expected actual values. The 385 pound load also creates tension in the vertical I-beam segments. The cross sectional area of the S8 I-beam is 5.4in^2 and the resulting tension is 71.3psi which is acceptable for Type 6061 aluminum.

The chamber assembly will be inserted into the beam line by resting the ends of the bottom surface of the aluminum I-beam onto the top surface of a pair of cantilevered steel I-beams that beams that are part of an existing structure in the experimental hall. Once in place this aluminum I-beam will experience stress and deflection from the weight of the drift chamber. If treated as a beam supported on both ends subject to concentrated identical loads equidistant from center then the stress and deflection of the I-beam can be calculated using standard formulas:

Stress at center of constant cross section: $s = \frac{-Wa}{Z}$ **(3)**

Maximum deflection at center: $y = \frac{Wa}{24EI}(3L^2 - 4a^2)$ **(4)**

Where:
- W is the weight of each load (385-lb)
- L is the length of the beam(180 inches)
- a is the distance from the end to the load (41.4 inches)
- I is the moment of inertia of S8x6.35 beam (57.6in^4)
- Z is the section modulus
- E is the modulus of elasticity of 6061 aluminum

Substituting the values from Table 1 into equation (3) yields:

$$s = -\frac{385lb \times 41.4in}{\left(57.6in^4 / 4in\right)} = -1106.9lb/in^2$$

Likewise, substituting the values into equation (4) yields:

$$y = \frac{1}{24}\left[\frac{385lb \times (41.4in)}{10e6psi \times 57.6in^4}\right]\left[3(180in)^2 - 4(41.4in)^2\right] = 0.104in$$

The bending stress of 1106.9 psi and deflection of 0.104-in of the S8x6.35 I-beam are acceptable.

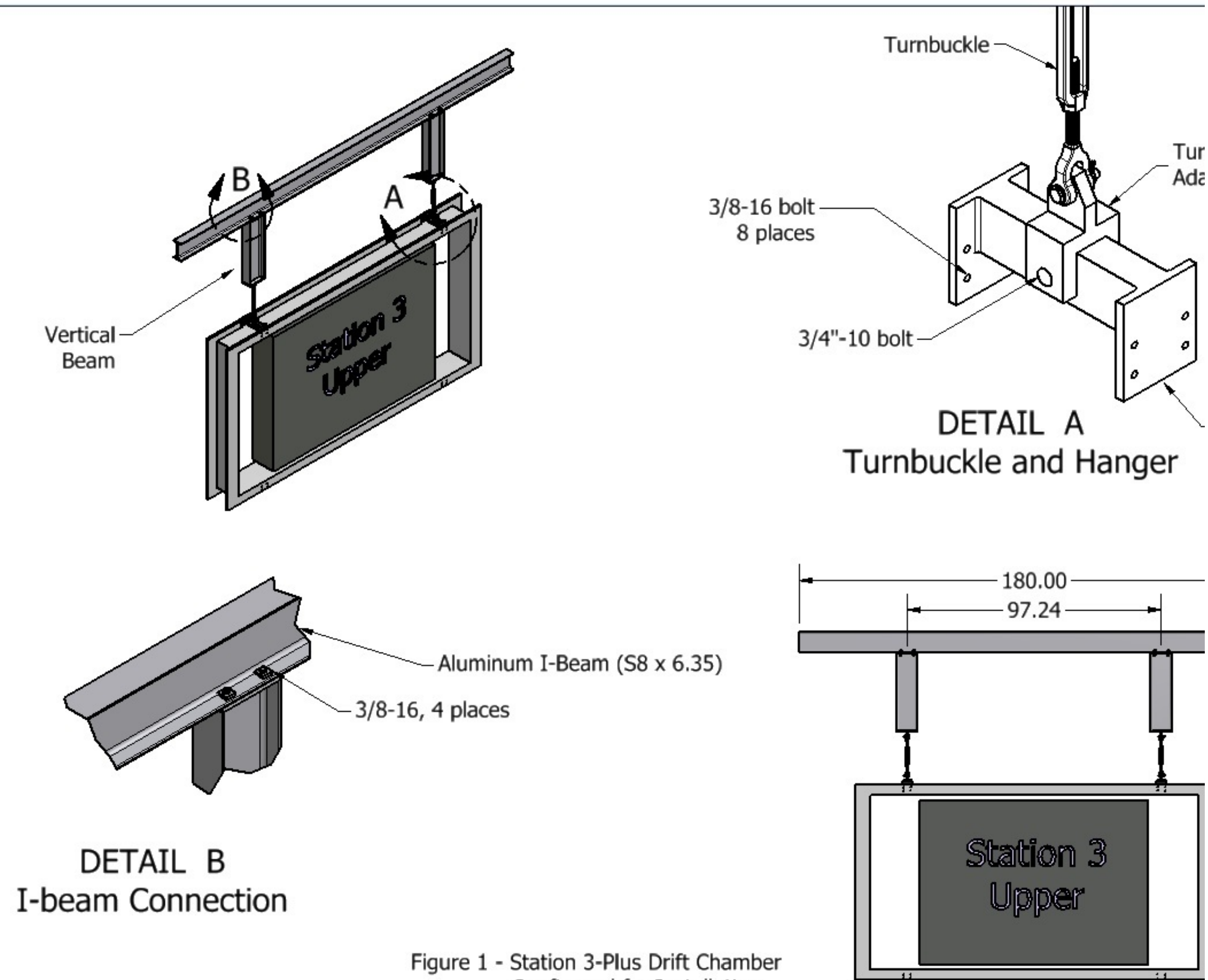
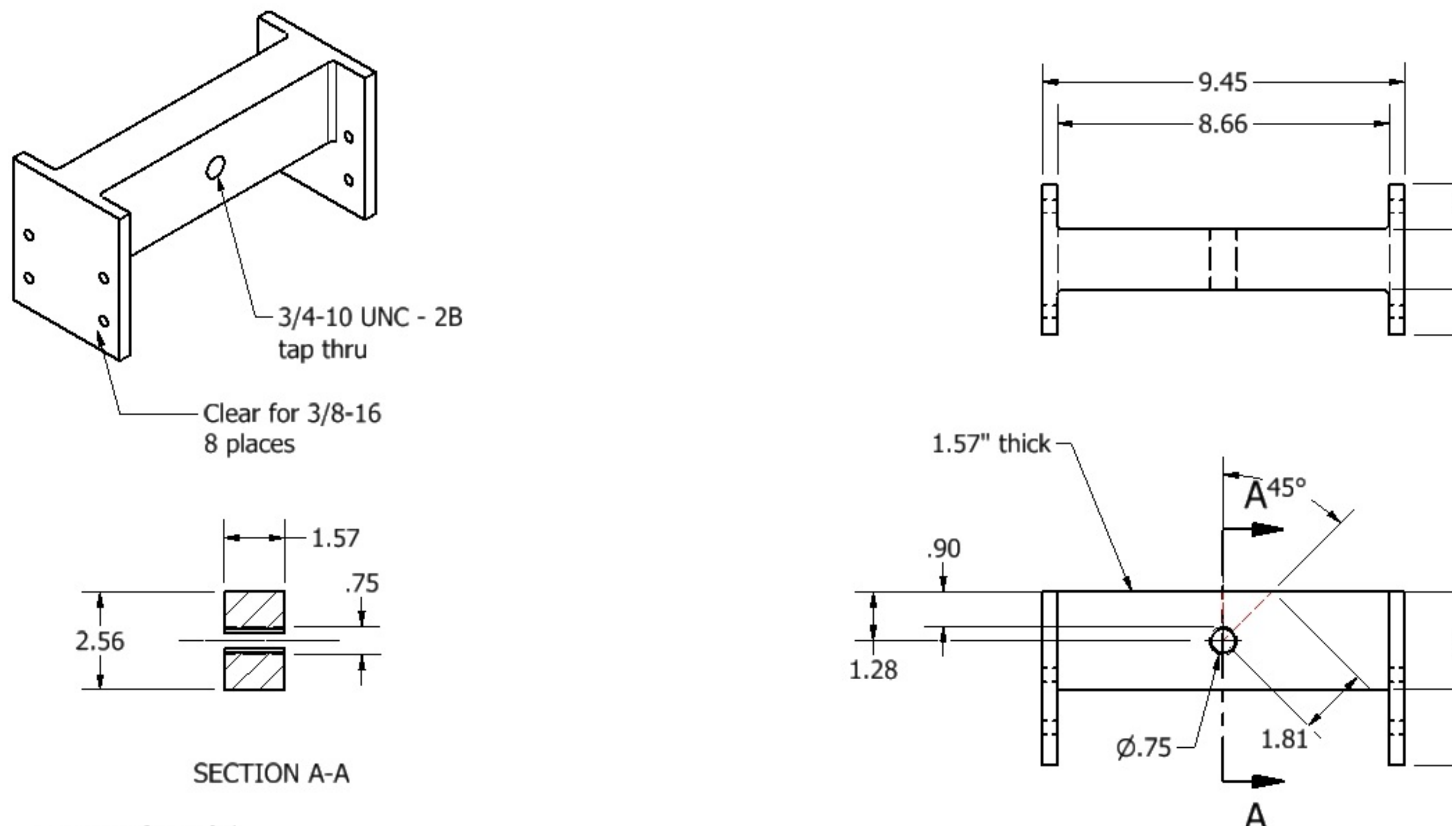


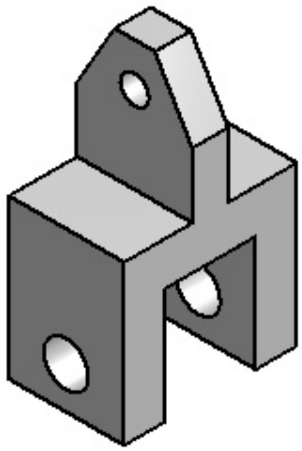
Figure 1 - Station 3-Plus Drift Chamber
Configured for Installation
Appriximate Weight = 770lb
(Excluding I-Beam)



Moment of Inertia*
Through the center of the tapped hole -
$I = 1.57(2.56^3 - 0.75^3)/12$
$= 2.14\text{-in}^4$
*Manual of Steel Construction, 9th Edition

Hole Tearout Analysis:
Load on 3/4-10 tapped hole = 385 pounds
Effective Cross Sectional Area:
A = 2(1.81)(1.57)
= 5.68-in^2
Shear on hole = 385/5.68 = 67.78psi

Figure 2 - Hanger Block, Steel S45C
Ultimate Tensile Strength = 81.9ksi, Yield Strength = 45ksi, E-mod = 29.1e8 psi



Hole Tearout Analysis:

Load on Ø.50 thru hole = 385 pounds

Effective Cross Sectional Area:

A = 2(0.48)(0.63)

= 0.60-in^2

Shear on hole = 385/0.60 = 641.67psi

Hole Tearout Analysis:

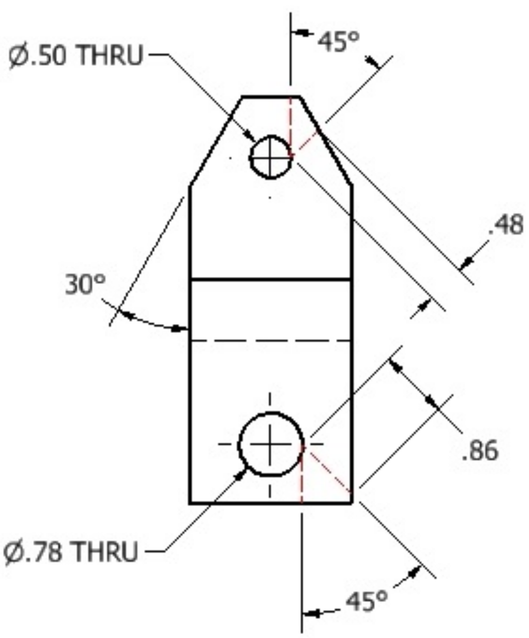
Load on each Ø.78 thru hole = 193 pounds

Effective Cross Sectional Area:

A = 2(0.86)(0.71)

= 1.22-in^2

Shear on hole = 193/1.22 = 158.20psi



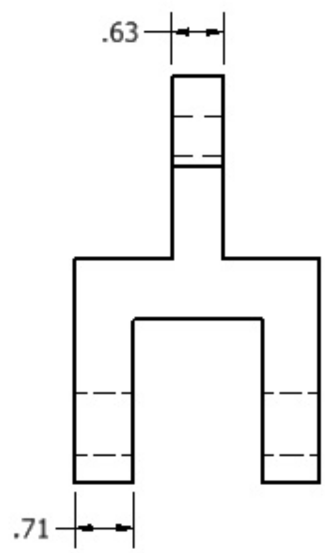
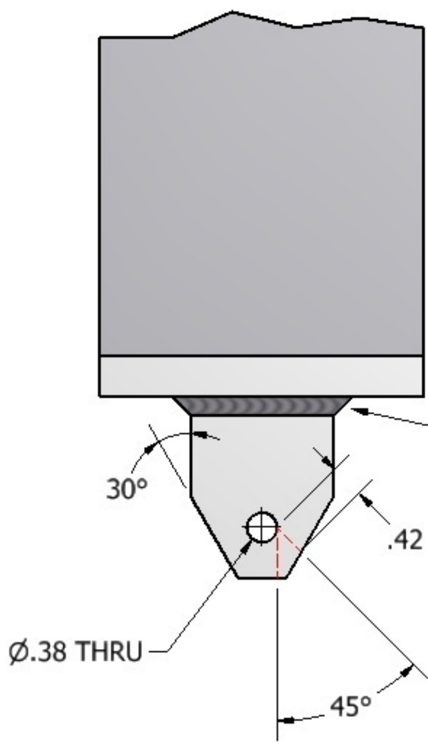
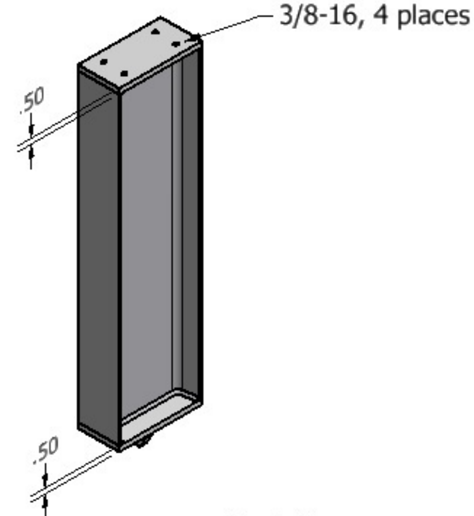


Figure 3 - Turnbuckle Adapter, Steel 1018

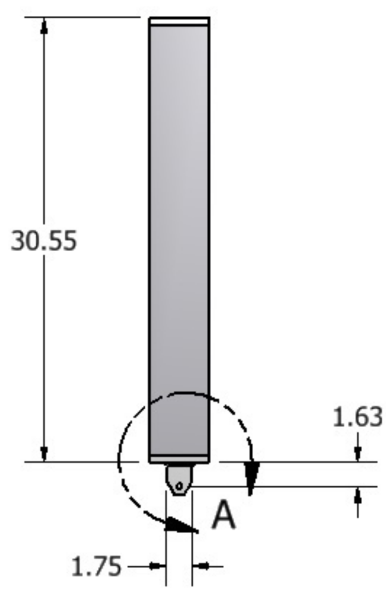
Ultimate Tensile Strength = 58ksi, Yield Strength = 32ksi

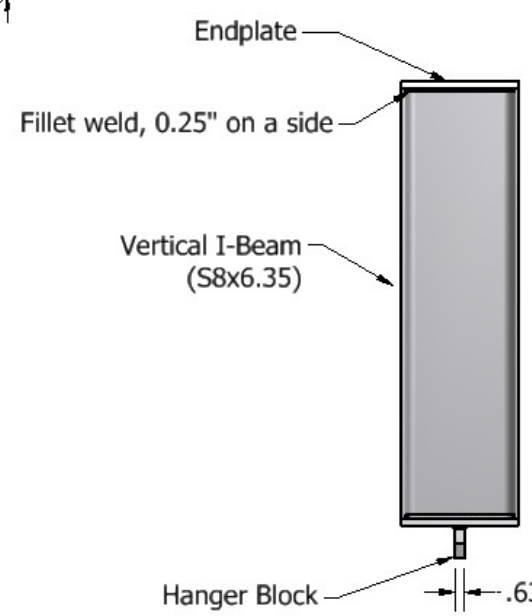
Allowable Shear = 0.4(32) = 12.89.9ksi





Fillet weld, 0.25" on a side





Hole Tearout Analysis:

Load on Ø.38 thru hole = 385 pounds
Effective Cross Sectional Area:
A = 2(0.42)(0.63)
= 0.53-in^2

Shear on hole = 385/0.53 = 726.42psi

Figure 4 - Vertical Beam, Aluminum 6061